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HOSE CHAFE GUARD TESTS

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Fort Eustis, Virginia

April 1974

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This report presents the results of a series of tests conducted to determine the operational suitability of using nylon 6/6 spiral-cut tubing (coil) as a hose chafe guard on Army helicopters. These tests were part of a follow-on effort recommended in USAAMRDL Technical Report 72-1. The test effort was divided into five areas: coil back-off tests; flight tests; temperature/wear tests; fluid compatibility tests; and ozone, aging, and fungus investigations. Test results and material investigation indicated that nylon 6/6 spiral cut tubing is a good hose chafe guard for the temperature band from −65° to 225°F, and it is recommended for retrofit to Army helicopters where temperatures do not exceed those bounds.

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PREFACE

The tests reported herein were conducted under DA Task 1F262203AH8603, "Reliability/Environmental Technology," House Task RM70-13. This task is part of the reliability and maintainability effort at the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia.

Technical assistance and advice were provided by Mr. Roger B. Hayman, Jr., Equipment Specialist, and Mr. Dominic P. Iannuzzi, Engineering Technician, both of the Eustis Directorate, USAAMRDL; Mr. Robert C. Brown, Naval Mine Engineering Facility, Yorktown, Virginia; and Mr. Virgil Mingus, U.S. Army Aviation Test Board, Fort Rucker, Alabama.

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INTRODUCTION

During the design and mock-up evaluation phase of an aircraft development program, the aircraft's hydraulic, fuel, and oil system hose locations and routing and the appropriate maintenance practices for that aircraft are established. Historically, the efforts of aircraft designers have not eliminated the possibility of the hoses' coming into contact with each other or the aircraft structure and causing chafing that could result in either forced or precautionary landings, incidents, or even accidents.

The monthly maintenance summaries published by the U.S. Army Agency for Aviation Safety (USAAAVS) have indicated a continual recurrence of hydraulic system failures due to chafed hydraulic hoses. These reports give no indication of time to failure, but they do highlight maintenance error as the primary contributor to the failures. Missing or improperly located clamps, incorrect clamp sizes, and twisted lines are a few of the maintenance errors noted by USAAAVS. Poor line routing, insufficient number of restraining clamps, and insufficient hose chafe guards are a few of the design errors noted.

A testing program was initiated by the Eustis Directorate of the U.S. Army Air Mobility Research and Development Laboratory to investigate methods of increasing hose life. The testing program was divided into two phases. Phase I was devoted to the investigation and selection of an appropriate hose chafe guard. The results of Phase I, presented in USAAMRDL Technical Report 72-1,[1] included the following conclusions and recommendations:

Conclusions:

1. The greater the contact force between wire-braided hoses, the shorter the time to failure or the mean-time-between-failures. However, chafing can be avoided by binding the hoses at the point of contact and, hence, precluding relative motion between the hoses.

2. Placing <u>any</u> covering over the wire-braided hoses increases their time to failure. The most effective coverings tested were spiral cut nylon 6/6 and nylon 6 coil tubing. They are easy to use, are resilient, retain their molded shape better than tetrafluoroethylene (TFE) coil (a widely accepted chafe guard), and are comparatively inexpensive. They have an excellent ability to withstand wear and will not inhibit the movement of hoses that must move due to hydraulic-actuator or some similar operation. The coils, in fact, might serve as good chafing indicators, since the nylon coil discolors at points of contact under vibration conditions.

3. Placing a nylon coil over the wire-braided hoses not only protects the hoses against chafing but also protects other components of the aircraft that might come into contact with a hose. Should a hose come into contact with an aircraft component, the nylon coil would be a much less abrasive surface to that component than bare wire braid.

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[1] Donald R. Artis, Jr., WIRE-BRAIDED HOSE CHAFING TESTS, USAAMRDL Technical Report 72-1, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1972, AD 738842.

Recommendations:

1. The following recommendations were made to reduce or eliminate the problem of chafing of wire-braided hoses in future U.S. Army aircraft.

   a. Amend those standards and specifications (such as MIL-H-27627) that describe design and test requirements for wire-braided hoses used on Army aircraft to account for chafing characteristics for those hoses that are qualified under that specification for use by future Army aircraft system developers.

   b. Initiate an effort to develop a chafe-resistant replacement for the wire-braided hoses currently used on Army aircraft.

2. The following recommendations were made to reduce damage caused by chafing of wire-braided hoses on current-inventory Army aircraft:

   a. Perform the following investigations to assure that general-purpose translucent nylon 6 (polycaprolactum) or 6/6 (polyhexamethylene adipamide) coil is a compatible and safe fix for the wire-braided hose chafing problem when installed on Army aircraft:

      (1) Determine the necessity for binding the nylon coil at each end when installed on a hose to assure that the coil remains in place.

      (2) Study the effects of high (> 100°F) and low (< 32°F) temperatures on the nylon coil's effectiveness as a chafe guard.

      (3) Perform a systems evaluation of the nylon coil's impact on effectiveness and service life by installing the coil on Army test aircraft.

      (4) Test the compatibility of the nylon coil with Army aircraft fluids and with those fungi to which the nylon would most likely be exposed.

   b. If tests show that nylon 6 and 6/6 coils are compatible when installed on Army aircraft, retrofit all Army aircraft with nylon coil chafe guards on wire-braided hoses.

Recommendation 1a has been deferred to higher headquarters for appropriate action. Recommendation 1b was accomplished by a contractor through a development program using a proprietary material. The results of that effort are given in USAAMRDL Technical Report 74-2.[2]

Phase II included operational suitability testing and evaluation of the selected hose chafe guard for use on Army helicopters, as recommended in 2a. This phase of the program is the subject of this report. Recommendation 2b is discussed further in the Recommendation section of this report.

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[2] ANTI-CHAFE HOSE, USAAMRDL Technical Report 74-2, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, February 1974.

OBJECTIVES

The objectives of the investigation described by this report are as follows:

1. Investigate the possibility of nylon spiral cut tubing (coil) backing off or uncoiling from a hose when used as a chafe guard to determine if the ends of the coil, once installed, need to be secured.

2. Conduct a flight test evaluation to determine the usefulness of nylon coil as a chafe guard under actual flight conditions.

3. Investigate the effect of temperature on the wear characteristics of nylon coil.

4. Investigate the compatibility of nylon coil with common Army aircraft fluids. In addition, investigate the wear characteristics of nylon coil following exposure to those fluids.

5. Investigate the possibility of adverse effects of fungus, aging, and ozone (0_3) on nylon coil.

Objectives 1 through 4 were accomplished via in-house testing at the Eustis Directorate; objective 5 was accomplished through an assessment of existing data.

PREPARATION FOR TEST

The only types of spiral cut nylon tubing that were commercially available for testing were made of either nylon 6/6 or nylon 6. The cost difference between the two types of nylon was not distinguishable in the small lots needed for this investigation (300 feet). Nylon 6/6 was slected as the type of nylon to be examined, since it has a higher melting point and deflection temperature than nylon 6. Both melting point and deflection temperature are measures of material durability, with the higher temperature values representing the more durable materials. The melting point for nylon 6 is 390° to 425°F; for nylon 6/6, 482° to 500°F. The deflection temperature for nylon 6 is 130°F; for nylon 6/6, it is 220°F under a deflection pressure of 264 psi.[3]

If nylon 6/6 is to be used in applications where temperatures can reach 225°F, a heat stabilizer must be added to the nylon. Therefore, for all the tests conducted during this investigation, nylon 6/6 spiral cut tubing with a heat stabilizer added was used.

Those tests that required a vibration assessment generally were conducted using the test conditions described in USAAMRDL Technical Report 72-1.[1] Basically, those conditions were as follows:

- 100 hertz, 0.04-inch double-amplitude displacement
- Hose-to-hose orientation as shown in Figure 1

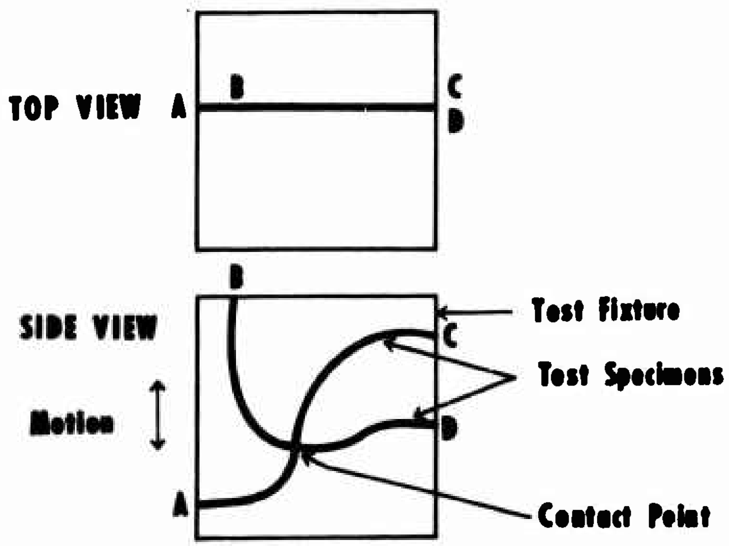

Figure 1. Hose test orientation (basic).

[3] ZYTEL NYLON RESINS DESIGN HANDBOOK, E. I. du Pont de Nemours & Co., Wilmington, Delaware, December 1972, pp. 14-15.

COIL BACK-OFF TESTS

Prior to flight testing, it was necessary to investigate the possibility that the nylon coil chafe guard would back off or shift if the ends of the coil began to unwrap. Figure 2 shows the method used to wrap the hoses for the coil back-off tests. Each hose was covered with nylon coil cut to fit within 1/8 inch of each hose end fitting. The coil was then unwrapped at least two full turns from each end, and the ends were left hanging free. The hose with nylon coil chafe guard installed was placed in the test fixture, and four hose orientations were examined as shown in Figures 3, 4, 5, and 6. Each test fixture with hoses installed was then placed on a vibration head and subjected to the following vibration conditions:

- Constant acceleration of 20g
- Cycle from 50 to 5000 hertz and return in 1 hour

The test fixture with a nylon-coil-covered hose in place was examined after a 1-hour exposure to the vibration conditions noted above. An unsatisfactory performance for the coil was defined as follows: at least one full spiral of the coil unwrapping from the hose plus the original two spirals of coil unwrapped at the beginning of each test.

No backoff of the coils occurred during the test, as shown by Figures 3, 4, 5, and 6. This indicated that no securing of the ends of the coils was necessary.

It should be noted that the proper size of nylon coil for the test hoses (size 6) was used for each test. Table 1 is a guide for determining the appropriate coil and clamp sizes to use with a particular wire-braided hose size. A test was made to determine whether a coil that was too small for the hose would back off. Figure 7 shows the results. No indication could be found that the coil backed off one full spiral.

TABLE 1. CORRELATION OF COIL AND CLAMP SIZES WITH HOSE SIZES

Wire-braided hose size*	Nylon coil size (OD, in.)***	Nylon thickness (in.)	MS 21919 clamp size: Tetrafluoroethylene insert	MS 21919 clamp size: Rubber insert
3	0.250	0.025	4	6
4	0.250	0.025	5	7
5	0.500	0.035	6	8
6**	0.500	0.035	7	9
8	0.500	0.035	9	11
10	0.750	0.045	11	13
12	0.750	0.045	13	15
16	0.750	0.045	17	19
20	1.000	0.055	21	23
24	1.000	0.055	26	28

*Sizes as specified in MIL-H-27267A, 13 July 196
**Test hose size
***Outside diameter of the unstressed nylon coil at standard atmospheric conditions

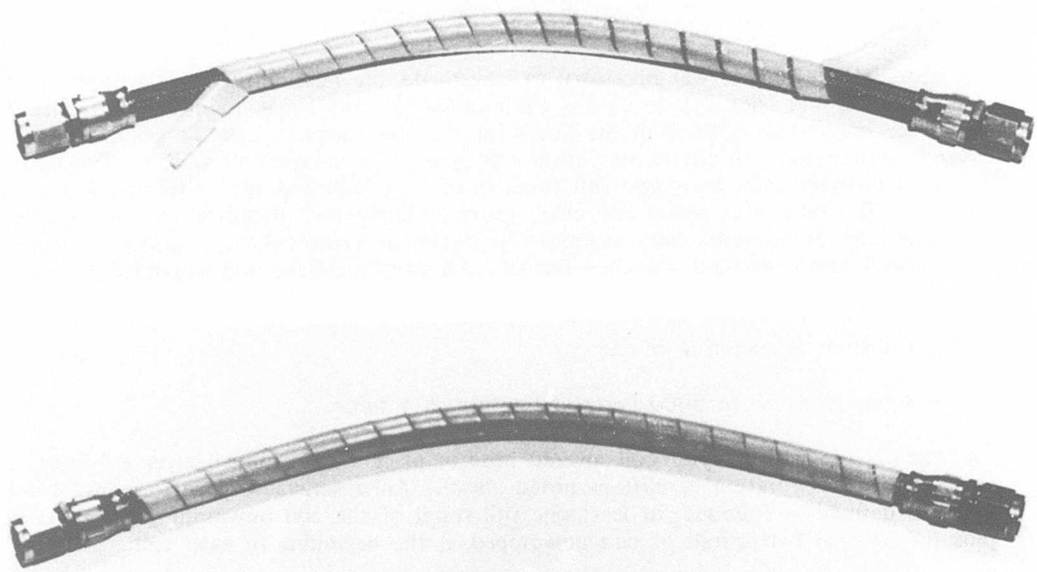

Figure 2. Nylon coil installation for coil back-off tests.

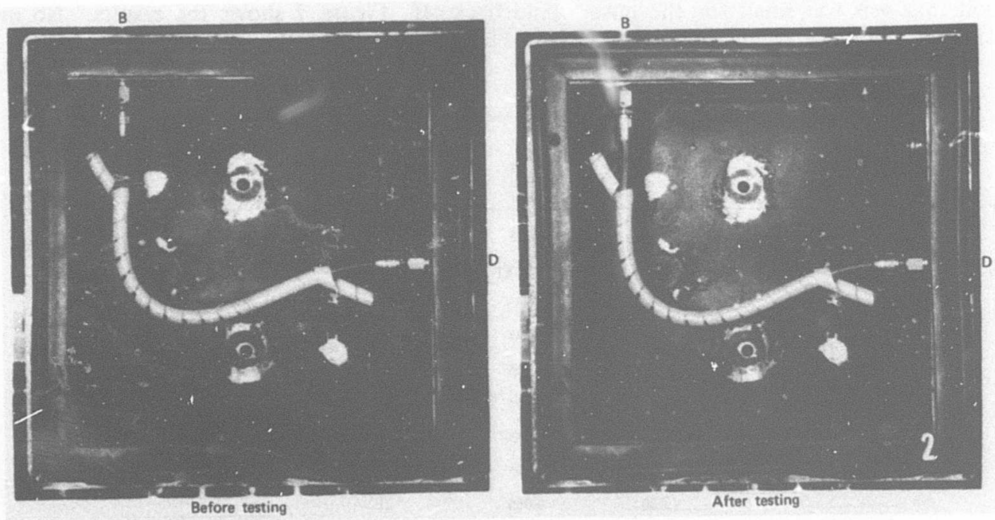

Figure 3. Coil back-off test (configuration B-D).

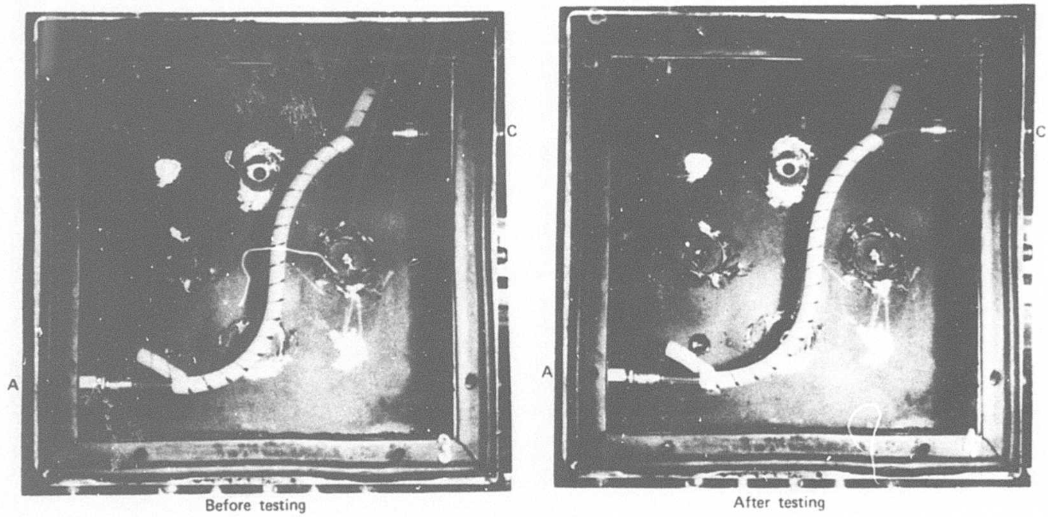

Figure 4. Coil back-off test (configuration A-C).

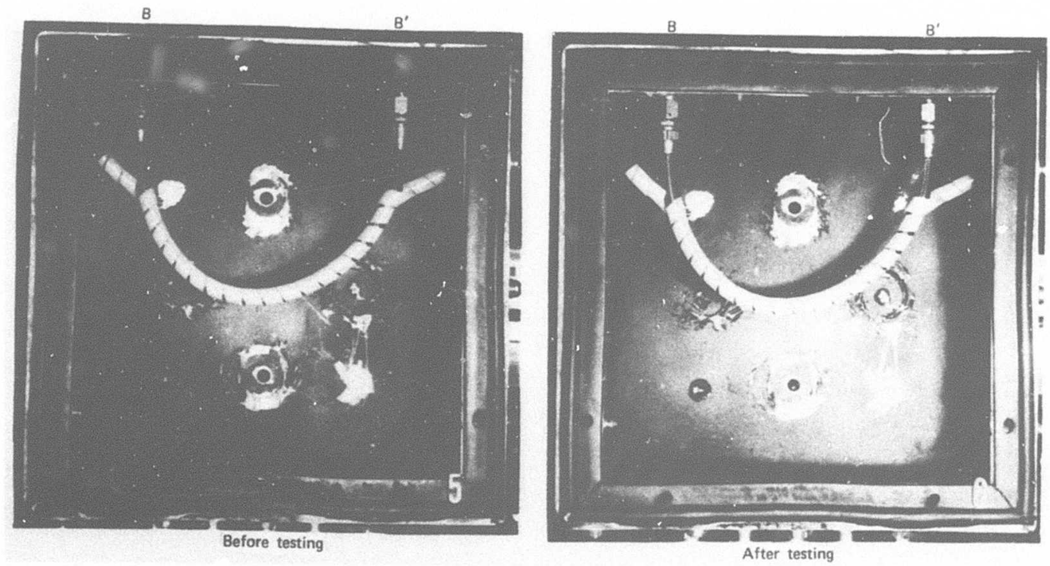

Figure 5. Coil back-off test (configuration B-B′).

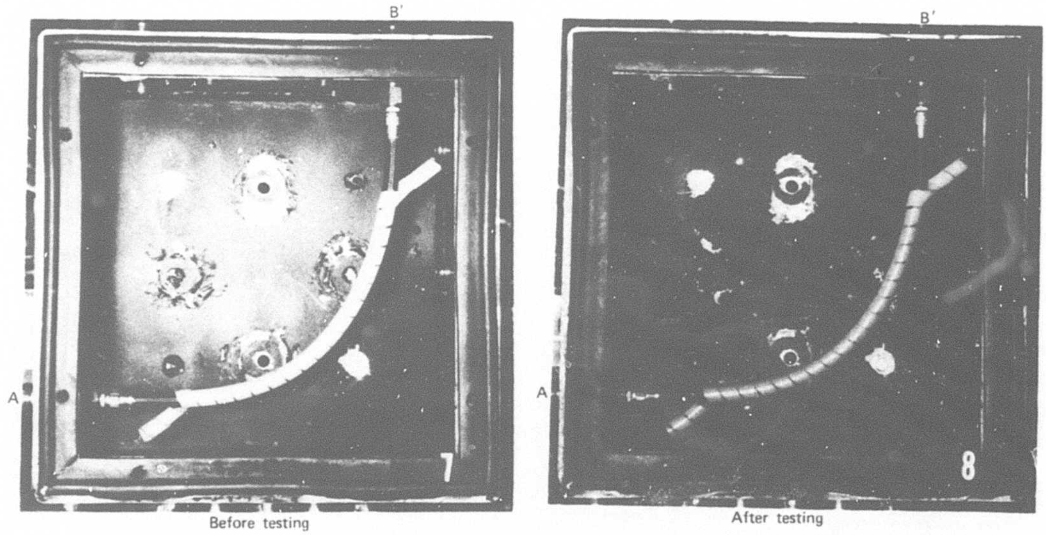

Figure 6. Coil back-off test (configuration A-B′).

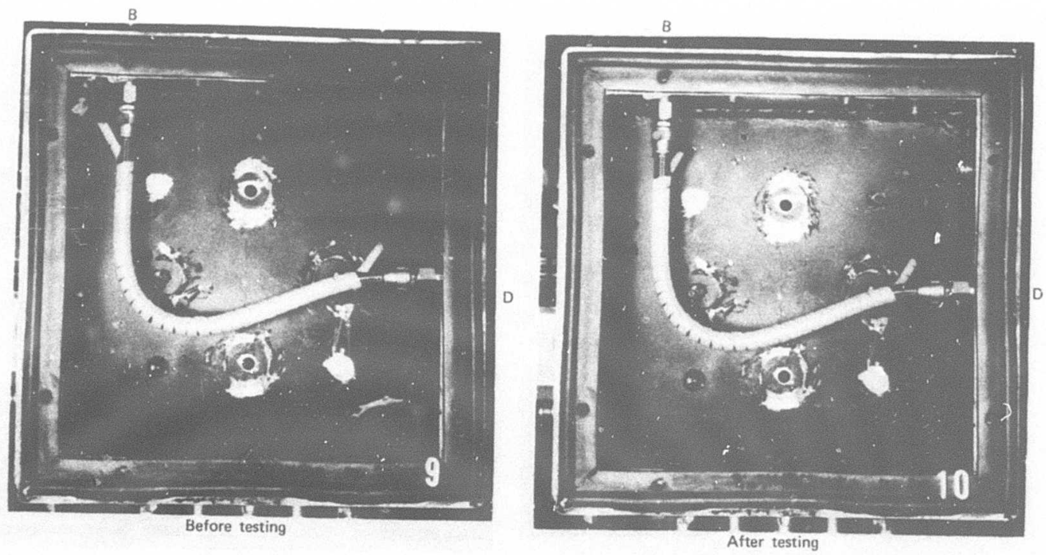

Figure 7. Coil back-off test (configuration B-D), incorrect coil size.

FLIGHT TESTS

Following completion of the coil back-off tests, a flight test evaluation was conducted by the U.S. Army Aviation Test Board, Fort Rucker, Alabama, to provide some insight into potential problems that may arise during actual use of the nylon coil as a chafe guard. The objective of the flight test was to determine whether the spiral cut nylon tubing (coil) would prevent two wire-braided hoses from contacting and, hence, chafing when the hoses covered with the nylon coil were purposely brought together at a single point of contact.

The approach was basically one of covering certain hoses on test aircraft with the nylon coil, inducing a point of contact by twisting the hoses against one another until a 1-pound contact force was attained, flying the aircraft under test conditions specified by the primary test user, and recording wear conditions on the nylon coil and/or hose at convenient times during the flight test. An attempt was made to obtain 300 hours of such test conditions per specimen. The flight test conditions were specified by the primary test user and not by the author, since the nylon coil flight test evaluation was conducted as an add-on test to aircraft already being used to perform flight test evaluations for other projects.

Table 2 and Figure 8 show the results of the flight tests. The nylon coil wear was random, varying from trace amounts to as much as 88 percent change in thickness. The wide variation was due to an inability to maintain a constant contact force between the hose specimens. However, the likelihood of the nylon coil's protecting a hose for at least 300 flight hours is very good, as shown by Figure 8.

TABLE 2. FLIGHT TEST RESULTS

Aircraft	Flight test time (hr)	Hose identification	Wear (Change in depth at point of contact) (pct)	Force (lb)
CH-47C	158:10	APU supply	10	Contact
CH-47C	158:10	APU start	10	Contact
CH-47C	183:05	APU supply	88	Contact
CH-47C	183:05	APU start	88	Contact
CH-47C	183:05	AGB pressure	5	Contact
CH-47C	183:05	Utility support system, upper	11	Contact
CH-47C	183:05	AGB return	11	Contact
CH-47C	183:05	Utility support system, lower	13	Contact
CH-47C	235:40	APU supply	50	Contact
CH-47C	235:40	APU start	50	Contact
CH-47C	271:20	APU supply	Trace	Contact
CH-47C	271:20	APU start	7	Contact
CH-47C	271:20	AGB pressure	37	Contact
CH-47C	271:20	Utility support system, upper	39	Contact
CH-47C	271:20	AGB return	10	Contact
CH-47C	271:20	Utility support system, lower	24	Contact
AH-1G	20:45	No. 2 pump supply	Trace	1.00
AH-1G	20:45	No. 2 pump pressure	Trace	1.00
UH-1M	274:30	Accum bypass	Trace	1.25
UH-1M	274:30	Accum supply	Trace	1.25
UH-1M	380:55	Accum supply	10	1.25
UH-1M	380:55	Accum bypass	Trace	1.25

AGB - Auxiliary gearbox

APU - Auxiliary power unit

Accum - Accumulator

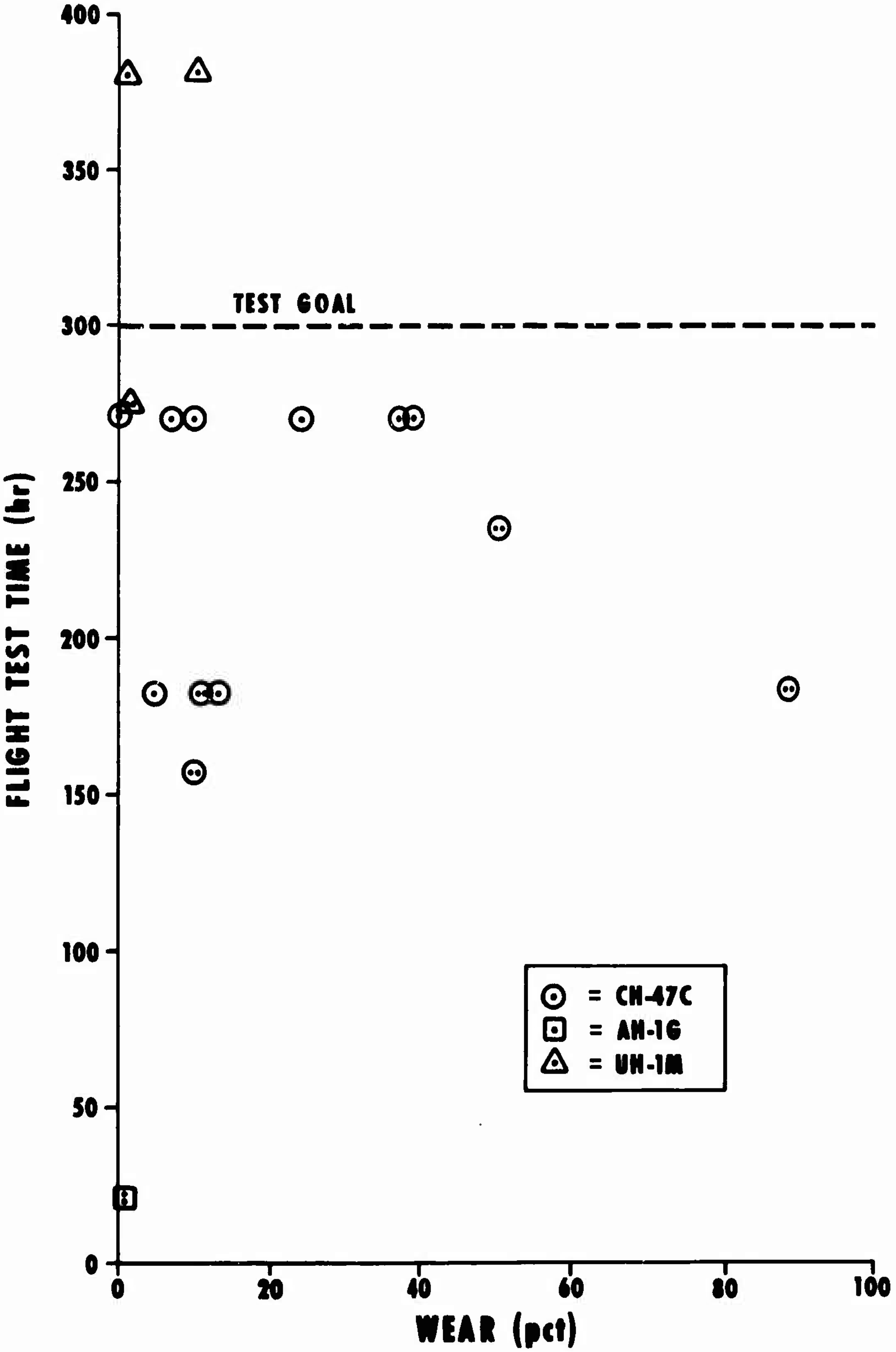

Figure 8. Percentage of wear versus flight test hours.

TEMPERATURE/WEAR TESTS

The temperature limits for the nylon chafe guard were specified and verified for acceptability during this program to ensure the effectiveness of the chafe guard. Conditions specified by U.S. Army Regulation 70-38, "Research, Development, Test and Evaluation of Material for Extreme Climatic Conditions," 5 May 1969, were used as a basis for low-temperature testing (< 32°F) of the nylon chafe guard. The extreme cold temperature conditions stated in that regulation include a range of from −60° to −70°F. Therefore, −65°F was selected as the low-temperature design and test point for this investigation.

The highest temperature for the high-temperature testing (> 100°F) of the nylon chafe guard was established at 225°F, based on the following rationale:

- According to U.S. Army Engineer Topographic Laboratories (USAETL) Report ETL-SR-73-2,[4] no ambient, closed compartment temperatures greater than 250°F have been recorded. The 250°F temperature was measured for storage conditions and not for operating conditions.

- Localized temperatures in certain areas may be greater than 250°F, e.g., next to the combustor and exhaust of an aircraft turbine engine. Temperatures of 250°F or more are rare, however, and are fairly easily isolated and designed against.

- According to USAETC Report ETL-SR-73-2, an air temperature of 160°F is a more realistic value of the extreme upper temperature most likely to be encountered in an unventilated Army aircraft compartment. An unventilated or closed compartment is the worst case for this application; hence, a 160°F air temperature was used as an input to determine the upper test temperature.

- Of the two types of hydraulic systems defined for Army aircraft in MIL-F-5440 (the standard used by the U.S. Army for designing aircraft hydaulic systems), the highest fluid temperature allowed is 275°F. Therefore, a fluid temperature of 275°F represents the worst case for this application.

- The upper test temperature was determined by averaging the worst-case hydraulic fluid temperature and worst-case unventilated compartment temperature as defined above.

- The average of those two temperatures is 217.5°F. That value was arbitrarily increased to 225°F to make the test conditions more severe.

Only ambient temperatures (not fluid temperatures) were used to determine the low-temperature test limit because the coil could attain the low temperature prior to a flight.

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[4] John Viletto, Jr., WORLDWIDE DISTRIBUTIONS OF AMBIENT TEMPERATURES AND TEMPERATURES OF MATERIAL EXPOSED TO DIRECT SOLAR RADIATION, ETL-SR-73-2, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, January 1973.

On the other hand, in determining the upper test temperature, the coil is not likely to stabilize at the upper fluid temperature of 275°F due to the cooling effects of the compartment, or ambient, air. The coil could have been stabilized at the unventilated compartment high temperature of 160°F prior to a flight; as the flight progressed, the temperature would increase but not to the fluid temperature of 275°F.

Figure 9 shows the orientation of the hoses for the temperature/wear tests. The test program consisted of combined temperature/vibration tests using the test fixture shown in Figure 9 and a different set of test specimens (nylon coils) for each test using the following test parameters:*

- Vibration input of 100 hertz and a 0.04-inch peak-to-peak displacement
- Test duration of 27.7 hours at each temperature
- Test temperatures of −65°, −30°, 130°, 160°, and 225°F

Each nylon coil sample was weighed, dimensioned, and visually inspected at the point of contact both before and after each test to determine wear. Photographs showing the point of contact and the resulting wear patterns were taken at the conclusion of each test. Representative test samples are shown in Figures 10, 11, and 12.

The temperature/wear tests revealed the following:

1. The samples tested at extreme cold temperatures (−65° and −30°F) showed less wear than those tested at elevated temperatures. This indicates that ambient cooling prevented heat buildup due to friction.

2. The most apparent adverse effect (carbonization) was obtained at 130°F vice 160°F or 225°F. Therefore, elevated temperatures (up to 225°F, at least) are not as significant a factor as frictional heat. The nylon carbonized at 130°F and at no other temperature examined for effect. Figures 10 through 12 present photographic coverage of carbonization. No attempt was made to investigate why carbonization occurred at 130°F. However, carbonization is believed to be the result of concentrated heat buildup due to friction. Therefore, 130°F represented the most severe test temperature and was used as the temperature for any additional testing that followed the temperature/wear tests.

3. Analysis of the test samples at 225° and −65°F by infrared spectroscopy revealed no significant difference in comparison to a control sample, indicating that these temperature extremes did not cause significant degradation of the chemical properties of the material.

*Same test parameters cited in Reference 1.

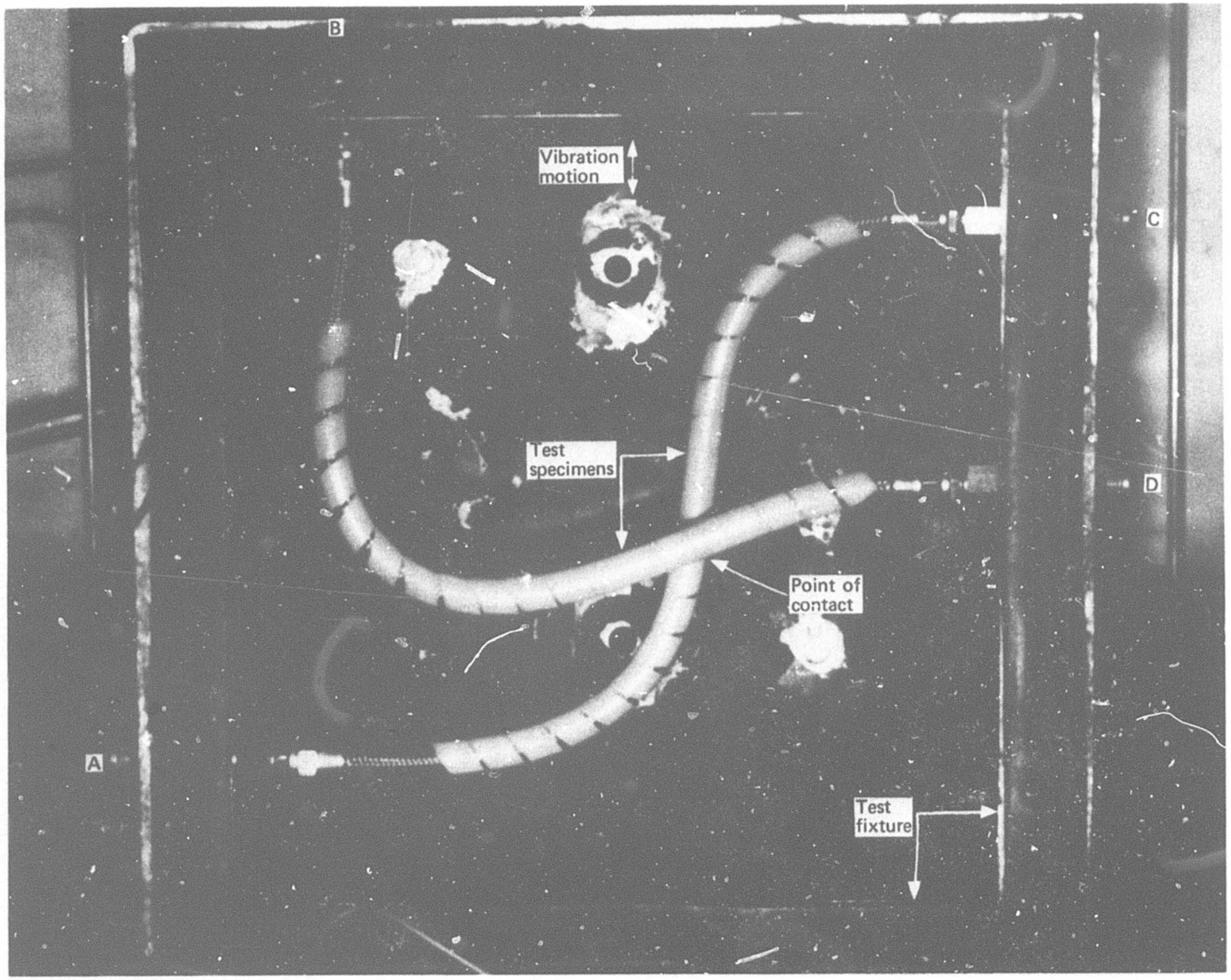

Figure 9. Temperature/wear test hose orientation.

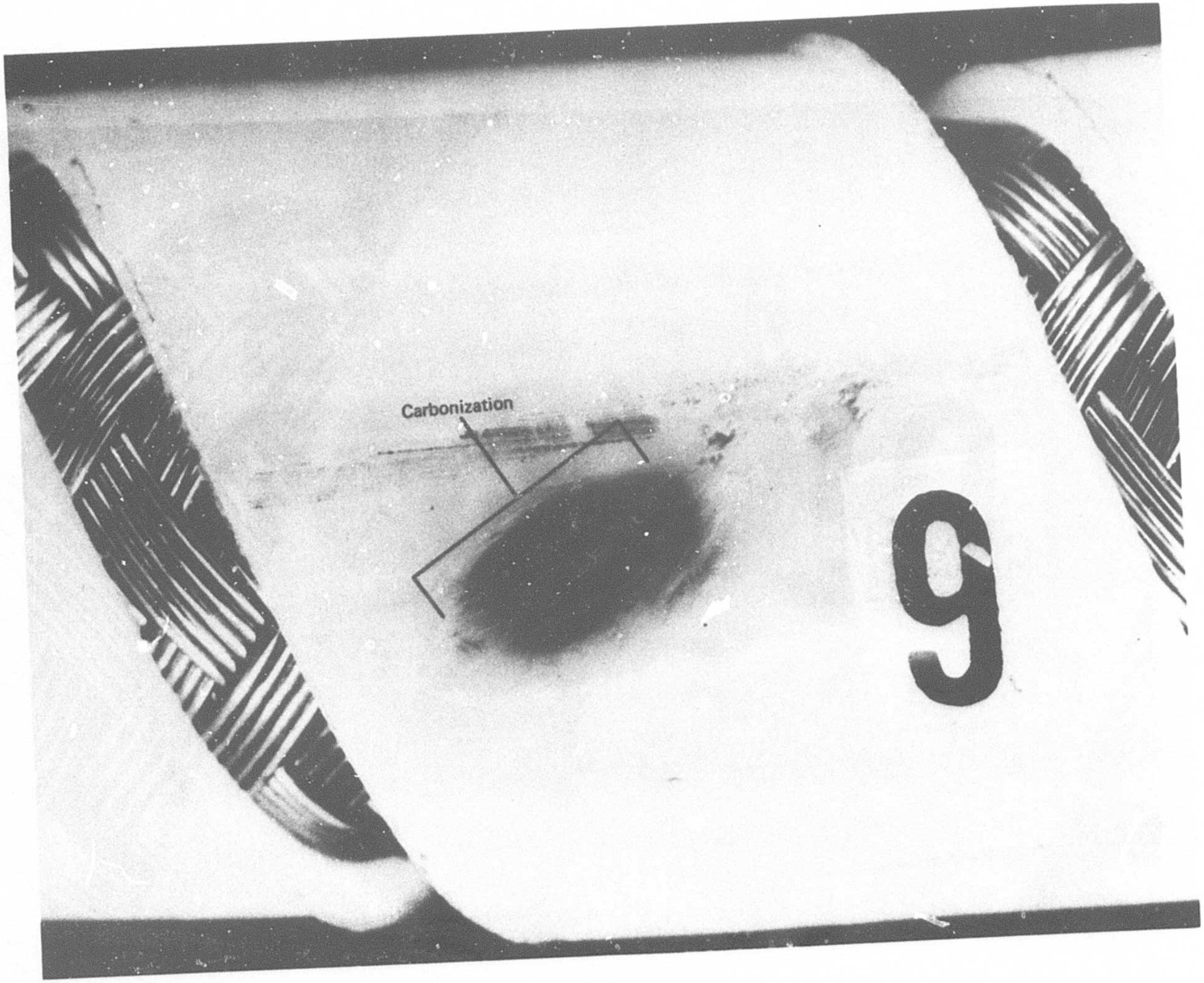

Figure 10. Carbonization at 130°F, test sample 9.

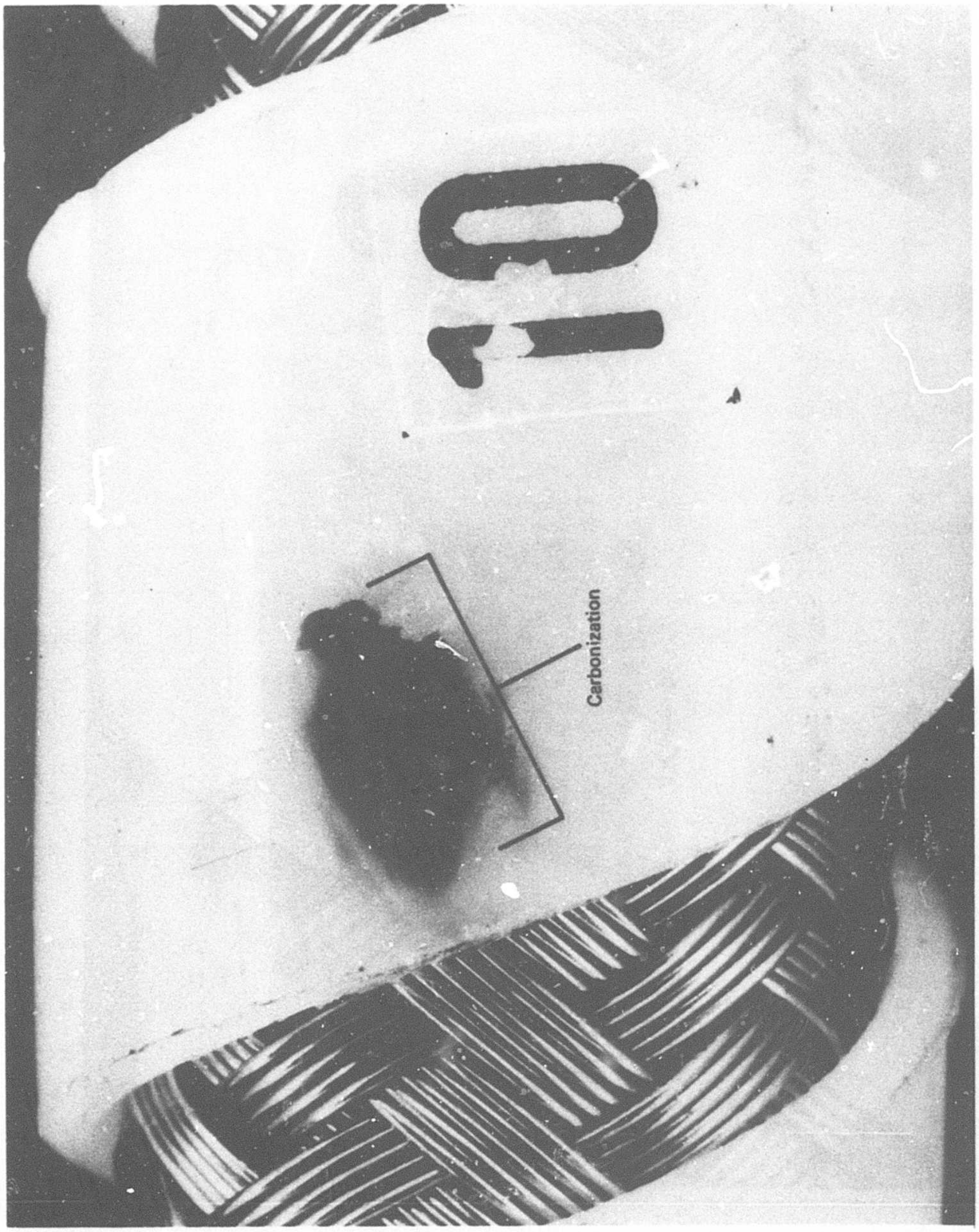

Figure 11. Carbonization at 130°F, test sample 10.

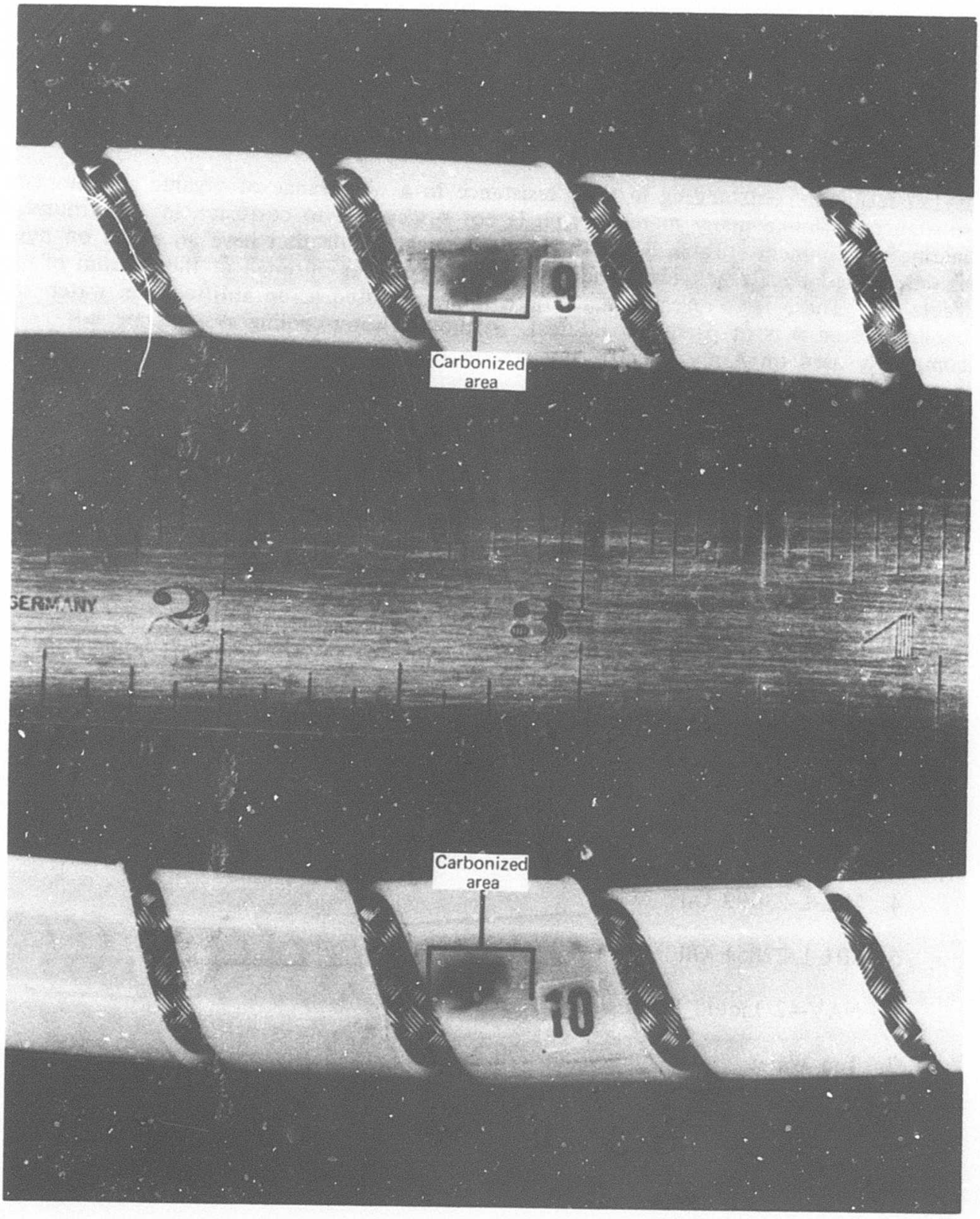

Figure 12. Carbonization at 130°F, test samples 9 and 10.

FLUID COMPATIBILITY TESTS

GENERAL

Following the determination of the temperature/wear characteristics of the nylon coil when used as an Army aircraft hose chafe guard, the compatibility of nylon 6/6 with Army-aircraft-type fluids was examined to determine any possible adverse effects.

Nylon resins are outstanding in their resistance to a wide range of organic and inorganic substances. Unlike many metals, nylon is not susceptible to corrosion in and around a marine environment. Table 3 shows those chemical agents that have an effect on nylon as determined by a crack test conducted by Du Pont, as outlined at the bottom of Table 3.[5] These tests revealed that ethylene glycol (used as an antifreeze in water-cooling systems) is of particular interest. Although water-cooling systems are not commonly used on Army aircraft, any system that uses ethylene glycol would require extra care to ensure adequate protection against chafing or spillage, since the agent could adversely affect the nylon material. Use of nylon as a chafe guard would not be recommended for such systems. The solvent-crack test described in Table 3 was not considered to be entirely representative of the conditions that would be encountered in actual service on Army helicopters. However, the test can be used to make comparative judgments.

TEST PROCEDURE

Certain fluids were judged to be worthy of examination for potential adverse effects on the nylon coil before it is recommended for use as an Army aircraft hose chafe guard:

1. MIL-H-5606 Hydraulic Fluid
2. MIL-H-83282 Hydraulic Fluid
3. MIL-H-7808 Oil
4. MIL-L-23699 Oil
5. MIL-L-22851 Oil
6. NAV-42 Liquid Detergent
7. Tap Water
8. MIL-T-5624 Fuel (JP-4)
9. MIL-T-5624 Fuel (JP-5)

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[5] DESIGNING WITH ZYTEL NYLON RESIN, E. I. du Pont de Nemours & Co., Wilmington, Delaware, December 1970, p. 17, Table 6.

TABLE 3. SOLVENT-CRACK EFFECTS* ON NYLON 6/6 RESIN

Agents having no effect		Agents having solvent-crack effect
Test conditions: 170°F for 30 days		
1% Sodium hydroxide	Acetamide	5% Sulfuric acid
Saturated sodium chloride	Nitrobenzene	Lactic acid
Toluene	Ethyl propionate	5% Sodium hydroxide
Heptane	Furfural	Ethylene glycol
Mineral oil	Dimethyl aniline	
Lubricating oil (SAE-20)	Oleic acid	
Butyl alcohol	Thiophene	
Butyl acetate	Castor oil	
Xylene	Cyclohexanol	
Chlorobenzene	Cycloheanone	
Benzaldehyde	Cyclohexane	
Aniline	Acetic acid	
Hydrogenated vegetable oil		
Soap solution		
5% Benzene in SAE-20 oil		
Dimethyl formamide		
50% Caprolactum solution		
Test conditions: room temperature for 30 days		
All those listed above having no effect plus		All those listed above having an effect plus
95% Ethyl alcohol	Turpentine	Concentrated hydrochloric acid
Carbon tetrachloride	Benzene	
Acetone	Bromine water	
Chloroform	2% Sodium sulfate	
Methyl phenyl		

*Test consisted of bending a bar 1.5 inches long by 0.5 inch wide by 0.12 inch thick, with a 0.020-inch-deep nick across the 0.5-inch face, so that the nicked face was in tension. The bent bar was inserted in a test tube 16mm in diameter. If the specimen cracked, the solvent was noted as having "solvent-crack effect."

10. P-D-680 Type I (Varsol)

11. VV-K-211 Kerosene

A fluid compatibility test that included a 30-day exposure period at both room and elevated temperature conditions was devised. Inside and outside diameters and weight were measured for each specimen both before and after the exposure periods. Any unusual occurrence during the tests was photographed. The fluid compatibility tests were conducted generally as follows:

1. Nylon coil test specimens were wrapped around metal tubes to place the outer surface of the coil in compression and its inner surface in tension (see Figure 13).

2. A nylon coil specimen and metal tube combination for each test fluid was placed in a container as shown in Figure 14 together with an 18-inch free specimen, i.e., not wrapped around a tube. Each container was filled with a fluid listed above (one container - one type of fluid).

3. Two exposure conditions were used to determine the effect of each fluid on the nylon coil: room temperature and elevated temperature. Room-temperature conditions were 70° ± 2°F for 30 continuous days. Humidity control was judged as not being significant, since the test specimens were submerged in a fluid. The elevated temperature conditions were 160° ± 2°F for 30 continuous days. Again, no humidity control was deemed necessary.

4. Room temperature tests were conducted for all the fluids (1 through 11), and elevated temperature tests were conducted for fluids numbered 1 through 7.

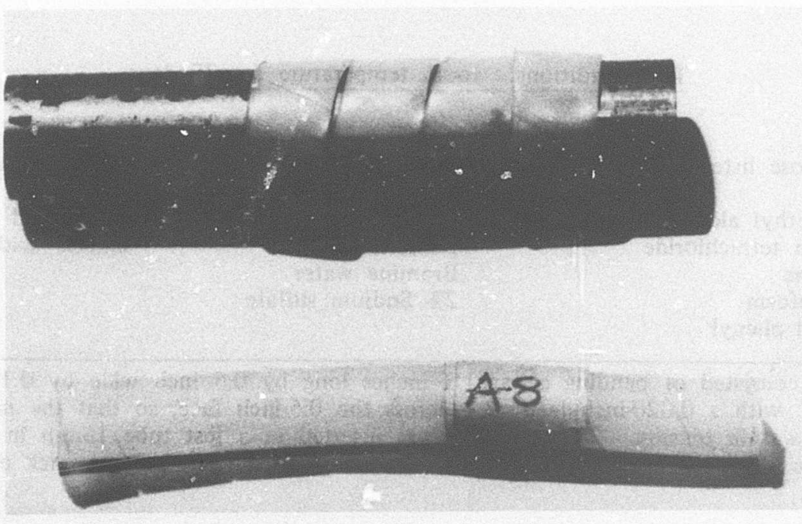

Figure 13. Four-inch nylon coil specimen.

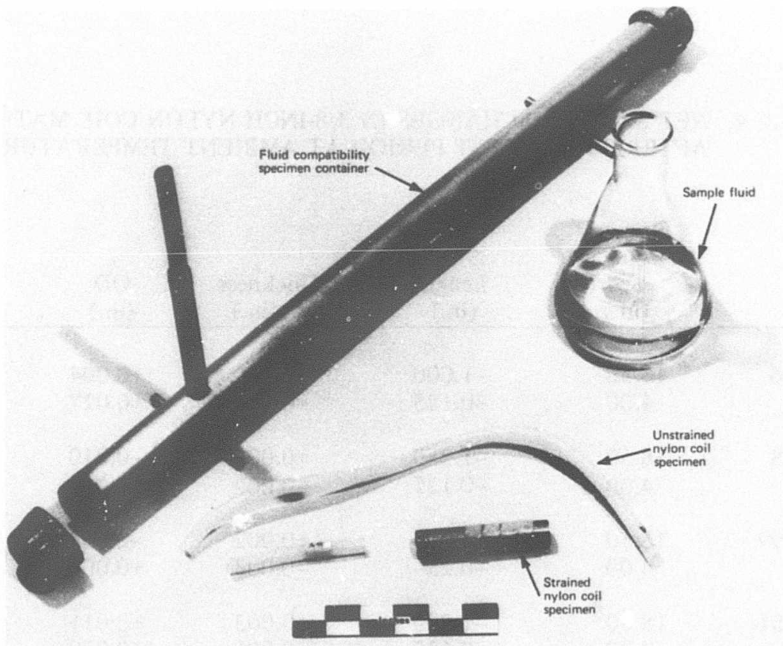

Figure 14. Fluid compatibility test apparatus.

TEST RESULTS

Visually Observed Changes

At the end of the 30-day soak period, the immersed nylon test specimens were visually inspected for discoloration or other noticeable effects. Color changes were the only visually detectable changes in the specimens. The most obvious color changes were induced by MIL-L-23699, MIL-H-5606, and MIL-L-22851 fluids, with the test specimens soaked in MIL-L-23699 fluid showing the greatest change from the normally white nylon coil. In addition, color changes of all the test specimens were greatest when subjected to the 160°F soak temperature.

Dimensional and Weight Changes of Fluid-Exposed Nylon Coil

Changes in nylon coil dimensions and weight following fluid exposure are shown in Tables 4 and 5. The measurements made are summarized below:

1. Ambient temperature conditions:

   a. Maximum linear shrinkage of the 18.50-inch-long test specimens was 1.25 inches.

TABLE 4. NET SPECIMEN CHANGES IN 3/8-INCH NYLON COIL MATERIAL AFTER 30-DAY TEST PERIOD AT AMBIENT TEMPERATURE

Test liquid	Original specimen size (in.)	Length (in.)	Thickness (in.)	OD (in.)	Weight (gm)
MIL-H-5606	18.50	−1.000	0	+0.004	0
	4.00	−0.125	−0.003	+0.027	0
MIL-L-7808	18.50	−1.250	+0.005	−0.010	−1.0
	4.00	−0.125	−0.002	+0.031	−1.0
MIL-L-23699	18.50	−1.00	+0.002	−0.003	0
	4.00	−0.25	−0.003	+0.009	−0.5
MIL-L-22851	18.50	−1.000	+0.003	+0.011	−0.5
	4.00	−0.125	−0.001	+0.029	−0.5
Tap water	18.50	−0.75	0	−0.020	0
	4.00	−0.50	−0.003	+0.121	0
NAVEE "42"	18.50	−0.625	−0.002	−0.016	0
	4.00	−0.625	−0.001	+0.103	−1.0
MIL-H-83282	18.50	−1.250	−0.003	−0.003	0
	4.00	−0.125	−0.001	+0.021	0
MIL-T-5624 (JP-4)	18.50	0	+0.001	+0.005	−1.0
	4.00	0	−0.004	+0.063	−0.5
MIL-T-5624 (JP-5)	18.50	−0.875	−0.004	−0.006	0
	4.00	−0.125	−0.004	+0.096	−0.5
P-D-680 (Varsol)	18.50	−1.000	+0.001	+0.005	−1.0
	4.00	−0.125	−0.001	−0.012	−1.0
Fed spec VV-K-2110 (Kerosene)	18.50	−1.25	+0.001	+0.002	−1.0
	4.00	−0.25	−0.001	+0.157	−1.0

b. Minimum linear shrinkage of the 18.50-inch-long test specimens was zero.

c. Thickness measurement changes of the 18.50-inch-long specimens varied from +0.005 to −0.004 inch.

d. Thickness measurement changes of the 4-inch-long specimens wrapped around 0.75-inch-diameter tubes ranged from −0.001 to −0.004 inch.

2. Elevated temperature conditions (160°F):

a. Maximum linear shrinkage of the 18.50-inch-long test specimens was 1 inch.

b. Minimum linear shrinkage of the 18.50-inch-long test specimens was 0.25 inch.

c. Thickness measurement changes of the 18.50-inch-long test specimens varied from +0.025 to −0.006 inch.

d. Thickness measurement changes of the 4-inch-long specimens ranged from +0.001 to −0.033 inch.

e. Outside diameter measurement changes ranged from −0.021 to +0.313 inch.

3. Net specimen weight changes were rather low. Measurement inaccuracies resulted in some inconsistent weight changes; e.g., 4-inch specimens lost weight while 18.50-inch specimens remained the same.

TABLE 5. NET SPECIMEN CHANGES IN 3/8-INCH NYLON COIL MATERIAL AFTER 30-DAY TEST PERIOD AT 160°F*

Test Liquid	Original specimen size (in.)	Length (in.)	Thickness (in.)	OD (in.)	Weight (gm)
MIL-H-5606	18.50	−0.25	+0.025	−0.024	−0.5
	4.00	−0.75	−0.033	+0.259	0
MIL-L-7808	18.50	−0.50	−0.001	−0.019	+0.5
	4.00	−0.50	−0.002	+0.265	0
MIL-L-23699	18.50	−0.25	+0.001	−0.013	0
	4.00	−0.75	+0.001	+0.284	0
MIL-L-22851	18.50	−0.750	−0.002	−0.015	0
	4.00	−0.375	−0.005	+0.254	0
Tap water	18.50	−0.75	−0.006	−0.014	0
	4.00	−0.75	−0.004	+0.283	0
NAVEE "42"	18.50	−0.50	0	−0.012	1.0
	4.00	−0.75	−0.002	+0.285	0
MIL-H-83282	18.50	−1.00	0	−0.021	0
	4.00	−0.50	0	+0.313	0

*The MIL-T-5624 fuels (JP-4 and JP-5), P-D-680 fuel (Varsol), and Federal Specification VV-K-2110 fuel (kerosene) were not examined at 160°F due to the volatility of these fluids and the inherent danger involved. Prior to initiation of testing, a room temperature examination was judged to be sufficient for those fluids.

WEAR TESTS OF FLUID-EXPOSED NYLON COIL

Following the fluid compatibility tests, certain fluid-exposed, unstrained, 18-inch-long test specimens were used to conduct additional wear tests similar to those conducted to determine the effect of temperature on the nylon. Those temperature tests, described earlier in this report, showed that 130°F was the most severe temperature of those examined (–65°, –30°, 130°, 160°, and 225°F) for the nylon coil used in this application. Therefore, a 130°F temperature was chosen for the wear tests of the fluid-exposed nylon coil. Three different fluid-exposed specimens were tested for wear effects induced by fluids which influence the measured or visual characteristics of the nylon coil:

1. Nylon coil exposed to MIL-H-5606 fluid (160°F, 30-day soak).
   Reason: MIL-H-5606 fluid caused the largest net change in thickness of the coils tested for fluid effect.

2. Nylon coil exposed to MIL-H-83282 fluid (160°F, 30-day soak).
   Reason: MIL-H-83282 fluid caused the largest net change in outside diameter of the coils tested for fluid effect.

3. Nylon coil exposed to MIL-L-23699 fluid (160°F, 30-day soak).
   Reason: MIL-L-23699 fluid caused the greatest color change of the coils (milky white to red) tested for fluid effect.

The wear test for the fluid-exposed test specimens consisted of subjecting the coils to a combined temperature/vibration test using the test fixture shown in Figure 9. The procedure was as follows:

1. Two sections of nylon coil were cut from the sample being tested. Each section was weighed, the thickness was measured at the contact point, and the outside diameter was measured before the coil sections (each section was approximately 9 inches long) were installed on the wire-braided hose. Each contact point of the specimens was then photographed.

2. Each of the test hoses was wrapped with the chafe guard from the same sample. The hoses were then mounted in the test fixture as shown in Figure 9 and were adjusted to provide a contact force of 4 to 4.50 pounds.

3. The test fixture with hoses installed was mounted to a vibration head inside a temperature chamber. The test fixture and hoses were then heat soaked at 130°F for a minimum of 30 minutes prior to the start of vibration testing.

4. The test fixture was vibrated at 100 hertz and 0.04 inch peak-to-peak displacement input conditions for 27.7 hours.

5. At the conclusion of the test, the test fixture and contents were allowed to return to ambient temperature, and the weight, thickness at the point of contact, and outside diameter of the nylon coil were measured and recorded. The general area of contact was then photographed again.

6. The tests were repeated for each of the three samples designated for these tests.

7. A sample of each of the nylon coils examined for wear characteristics was tested using infrared spectrophotometry and compared to a standard (nonfluid-exposed) sample.

Generally, none of the fluid-exposed samples subjected to the wear tests exhibited any wear sufficient to cause a loss of protection for the wire-braided hose (see Table 6). The wear patterns were not significantly different from those tested during the temperature/wear tests, indicating that the various fluids did not materially change the wear resistance of the nylon 6/6 material. In addition, the results of the infrared-spectrophotometry tests revealed no appreciable chemical change in the nylon 6/6 material after being subjected to the fluids that were known to have caused measured (dimensional) or visual changes in the nylon coil.

TABLE 6. COMPARISON OF WEAR CHARACTERISTICS OF NYLON 6/6 COIL FOR PARTICULAR FLUID-EXPOSED SAMPLES AT 130°F

			Fluid-Exposed Test Specimens					
	Control specimen (nonfluid soaked)		MIL-H-5606		MIL-L-23699		MIL-H-83282	
Measured parameter	Before test	After test	Before test	After test	Before test	After test	Before test	After test
Wall thickness at point of contact (in.)	0.0315	0.0300	0.0310	0.0160	0.0320	0.0310	0.0300	0.0280
Outside diameter (in.)	0.451	0.500	0.456	0.485	0.455	0.485	0.450	0.475
Weight (gm)	5.8	5.6	5.0	4.9	5.5	5.5	4.6	4.5

OZONE, FUNGUS, AND AGING CONSIDERATIONS

Additional general categories of interest applicable to the Army's use of nylon 6/6 coil as an aircraft hose chafe guard included ozone, fungus, and aging.

OZONE

Considerations that relate to nylon 6/6 include the potential for damage to the nylon as a result of aircraft-originated or naturally occurring ozone. However, ozone can be ignored for this application since testing conducted by E. I. du Pont de Nemours & Co. on a nylon sample at a concentration of 100 parts of ozone per million parts of air by volume at 104°F for 4.5 days showed that no cracking was induced for a specimen bent 180 degrees. The concentration of the ozone in the test was considerably higher than can reasonably be expected in the operation of Army helicopters. Concentrations are more likely to be on the order of 120 parts per million based on the requirements of MIL-H-26385B, "Hose Oxygen and Pressurization, Ozone Resistant", 15 November 1968. Also, the exposure times are likely to be intermittent and short compared to the test time (less than 1 hour for each exposure instead of approximately 100 hours).

FUNGUS

Considerations that relate to nylon 6/6 include the potential for damage to the nylon as a result of fungal growth. Nylon has been found by Du Pont (Reference 3, page 61) and the U.S. Army Natick Laboratories[6] to be resistant to attack from bacteria and fungi both in laboratory-type controlled tests and in burial tests. Test bars of nylon 6/6 that were exposed for 28 days to active fungal environments showed no visual evidence of attack, no loss in physical properties, and no changes in molecular weight. The fungi used for testing included the following:

- Chaetomium globosum
- Rhizopus nigricans
- Aspergillus flavus
- Penicillium luteum
- Momononiells echinata
- Penicillium janthinellum (pink staining occurred)

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[6] Morris R. Rogers and Arthur M. Kaplan, EFFECTS OF PENICILLIUM JANTHINELLUM ON PARACHUTE NYLON - IS THERE MICROBIAL DETERIORATION, Pioneering Research Laboratory, U.S. Army Natick Laboratories, September 1970.

AGING

Aging considerations that relate to nylon 6/6 include the change of the physical properties of the nylon with time. It was necessary to allow the nylon 6/6 coil to age for at least 1 year at standard atmospheric conditions before conducting the tests described by this report. Nylon undergoes changes in some of its physical characteristics, such as creep modulus, with time.[7] Figure 15 shows the time required to reach a fairly stabilized condition (10,000 hours at approximately standard atmospheric conditions) (Reference 7, page 186). All the nylon 6/6 specimens used in the tests described in this report were aged at least 10,000 hours before using. Creep modulus was used as the gage for adequate aging prior to testing because it is a means of easily defining and calculating the deformation to be expected when a part is under load for long periods of time.

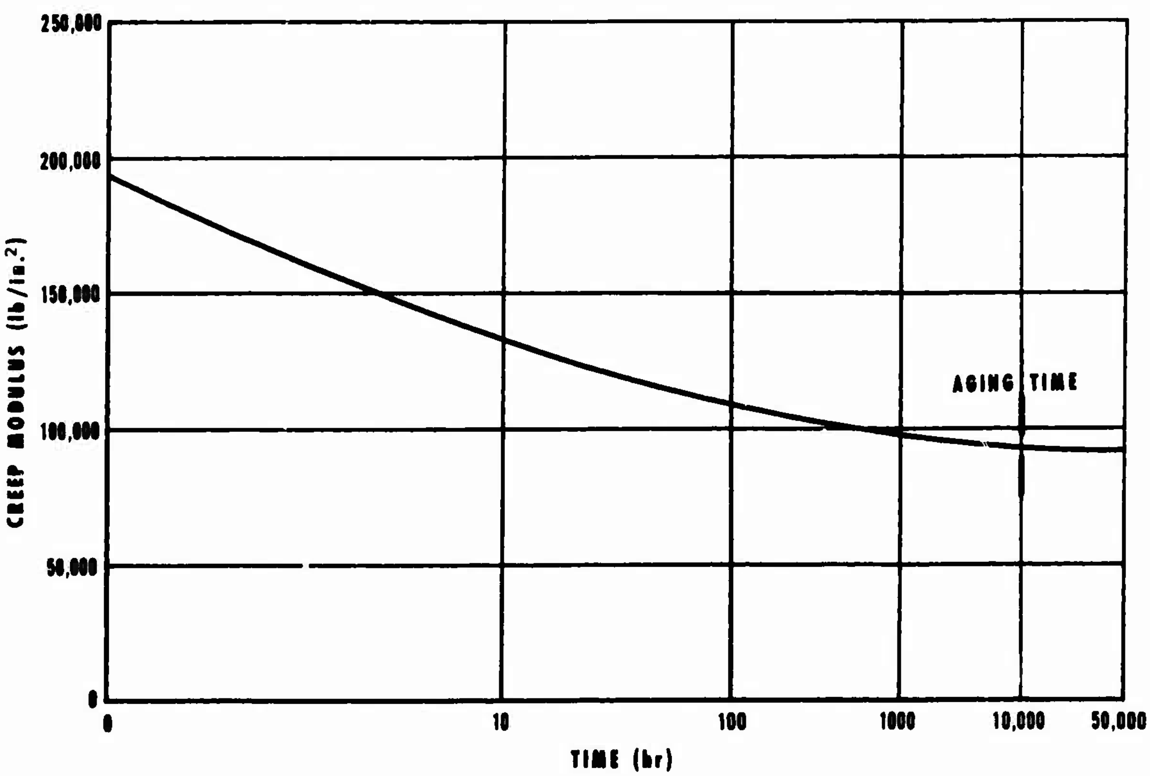

Figure 15. Creep modulus versus time for nylon 6/6.

[7]TECHNICAL DATA ON PLASTICS, Manufacturing Chemists Association, Incorporated, Section VII, Washington, DC, February 1957.

CONCLUSIONS

It is concluded that:

1. Nylon 6/6 spiral cut tubing could be used on Army helicopters as a hose chafe guard without any adverse operational problems.

2. Nylon 6/6 spiral cut tubing (coil) can be effectively used as a chafe guard on flexible hose without the ends of the tubing being secured. However, the correct tube size should be used for each hose (see Table 1).

3. Temperature has no adverse effects on the wear characteristics of nylon 6/6 coil with a heat stabilizer added. However, the operational limits for nylon 6/6 spiral cut tubing (heat stabilizer added) are –65°F and 225°F. Nylon 6/6 chafe guards should not be used in applications where temperatures exceed 225°F.

4. Nylon 6/6 is compatible with standard aircraft-type fluids and should not exhibit adverse effects from exposure to those fluids.

5. Ozone has no significant effect on nylon 6/6.

6. Fungus does not affect the strength characteristics of nylon 6/6, nor does nylon 6/6 support fungal growth.

7. The minimum strength value (stabilized creep modulus) of nylon 6/6 is attained following 10,000 hours of exposure to standard atmospheric conditions and no loading. Since all the tests discussed in this report were conducted using aged nylon 6/6 and since the nylon "passed" all the tests, the effects of aging or storage may be ignored when the usefulness of nylon 6/6 coil is assessed as a hose chafe guard for Army aircraft.

RECOMMENDATION

It is recommended that all the flexible hoses on Army helicopters be covered with nylon 6/6 spiral cut tubing (coil) with a heat stabilizer added to the nylon 6/6 when manufactured. Zytel 103HS, manufactured by E. I. du Pont de Nemours & Co., or the equivalent is acceptable as a hose chafe guard material. Table 1 should be used to determine the correct coil size for each hose size. Covering all the hoses would eliminate the need for an analysis to determine which hoses should or should not be covered. The weight addition to cover all the flexible hoses in an aircraft would be minimal (Example: 0.8 pound for the UH-1C, which has a dual hydraulic system). The only areas of an aircraft where the nylon 6/6 coil should not be used are those areas where the temperatures at or near the hoses would exceed 225°F, e.g., next to combustors of turbine engines. The nylon coil could be used until a chafe-resistant hose can be developed and introduced into the Army aviation supply channels.

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